Information Visualization on Interactive Tabletops in Work vs. Public Settings

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Fig. 1. Groups of people engaging in information exploration and analysis in work (left) and public settings (right).

Abstract— Digital tabletop displays and other large interactive displays have recently become more affordable and commonplace. Due to their benefits for supporting collaborative work—when compared to current desktop-based setups—they will likely be integrated in tomorrow's work and learning environments. In these environments the exploration of information is a common task. We describe design considerations that focus on digital tabletop collaborative visualization environments. We focus on two types of interfaces: those for information exploration and data analysis in the context of workplaces, and those for more casual information exploration in public settings such as museums. We contrast design considerations for both environments and outline differences and commonalities between them.

Index Terms—Digital tabletop displays, information visualization, information exploration, collaboration

1 Introduction

Groups of people often form decisions or gain knowledge about a topic by coming together in physical environments to discuss, learn, interpret, or understand information. These groups often make use of physical tables to view, share, and store visual information. These types of group tasks or goals commonly occur in meeting rooms, research labs, classrooms, museums, and other public settings. Digital tabletop displays can augment information exploration and analysis in these physical spaces; they can support the collaborative and interactive exploration of digital information beyond the possibilities that printed paper, projected slide shows, or non-interactive media such as posters, black-boards, or bulletin boards can offer.

In the remainder of the paper, we discuss the role of tabletop displays for collaborative information exploration or analysis in two specific contexts: work environments and public spaces. In work environments, such as meeting rooms or research labs, teams of analysts can be characterized by a vast amount of domain-specific knowledge, while in public spaces, such as museums or art galleries, people's level of knowledge on a certain topic varies and is difficult to predict or expect. Nonetheless, both contexts invite the possibility of gaining insight through the process of exploring and analyzing information. By looking at existing examples of information visualization in both contexts, we discuss their commonalities and differences in order to arrive at practical considerations for designing tabletop interfaces to support information exploration in each context.

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2 Tabletop Displays in the Workplace

In many areas, domain experts perform data analysis on a daily basis. For example, molecular biologists frequently analyse huge datasets from lab experiments, business analysts look at trends in financial data, or historians explore large document databases to bring historical events into context. With the rapid growth of the complexity and size of datasets in many work scenarios the need to support multiple people simultaneously viewing and manipulating data is increasing. This growth means that domain experts from different disciplines and with different skill sets are often required to collaborate, to make informed decisions about a dataset, and to improve the quality of an analysis result. Datasets on which decisions and discoveries are based may not only be too large to handle by a single analyst but may also be susceptible to a variety of interpretations, in which case experts may need to discuss and negotiate their interpretations of the data.

Digital tables offer great potential to support this type of work. In the near future digital tabletops may be installed in offices, meeting rooms, or research labs where today's domain experts already meet to discuss, interpret, and analyse data. One of the great advantages of tabletop displays in the workplace is their ability to support such collaborative work. Analysis systems that use digital tables can enable in-situ discussion, exploration, and interpretation—in close contact with the data and its visualization. Team members can work independently and together while being able to spontaneously react to findings in the data and to resolve data conflicts as a group. The design of interfaces, visualizations, and interaction techniques for visual analysis by teams of domain experts around tabletops is an active research area. At the time of this writing, examples of systems for exploring information at a tabletop display in the workplace have been limited mostly to research prototypes. As the cost of such systems goes down, we expect

to see more commercial examples arise. Nonetheless, the research prototypes demonstrate the viability of tabletop systems for improving people's ability to collaboratively explore information.

The authors have previous experience building system prototypes for information analysis in the workplace. Lark [12] was designed to help multiple analysts coordinate their individual and joint analysis activities on a tabletop (Figure 2-left). Cambiera [6] supported several collaborators foraging for information in large text document collections, highlighting overlap in found and accessed documents (Figure 2-middle). In another project [5] guidelines for collaborative information visualization were tested as a case study in a tabletop tree comparison system (Figure 2-right).

Fig. 2. Collaborative infovis systems built by the authors.

3 Tabletops in Public Spaces

Tabletop displays have started to become more common outside of research labs and work environments. For instance, we can find them in museums and art galleries where they are used to convey information to people in an interactive and potentially engaging way. The use of horizontal digital surfaces to present interactive data visualizations has several advantages, especially for more casual public settings where people gather in their spare time. Information visualizations presented on digital tabletops can turn abstract data into interactive exhibits that evoke attention and curiosity and entice visitors to take a closer look. The physical setup of tabletop displays enables visitors to approach the presented information from all sides; several groups or individuals can collaboratively explore, share, and discuss the data visualization. The ultimate goals of large horizontal information displays in public spaces are to attract people's attention, draw them closer to the installation, and promote lightweight information exploration that leads to serendipitous discoveries, some reflection on the presented data and/or active discussion of this data with peers.

We have previously presented and exhibited information visualization systems in public spaces. memory [en]code (Figure 3-left) is a tabletop system that visualizes the dynamics of human memories in an interactive way [9]. Visitors are invited to type their own thoughts or memories into the system. The participatory aspect of memory [en]code positively influenced people's engagement with the installation. The fact that all information was created by other visitors and the ability to leave personal traces within the system added a personal touch to the installation. EMDialog [3] is an interactive information installation that that was developed to enhance an art exhibition showing paintings from the artist Emily Carr. The installation presents two interlinked information visualizations that invite museum visitors to explore the extensive discourse about Emily Carr along temporal and contextual dimensions (Figure 3-right).

Fig. 3. Infovis systems by the authors exhibited in public spaces.

4 Designing for Work vs. Public Spaces

When designing visualization systems for collaborative information exploration, we are faced with a number of challenges in common with other tabletop work: the need to support awareness and common ground formation, perceptual problems, as well as collaborative interaction issues. However, several challenges also arise due to the nature of interaction with information visualizations. In this section, we discuss these challenges and point out the differences that need to be considered when designing for workplace and public settings.

4.1 Contextual Challenges

One of the main differences to consider when designing tabletop applications for workplace or public settings is the context in which the information is being accessed. While the context for workplace systems often goes hand-in-hand with well-defined tasks and goal-oriented analysis, the context for public settings can vary dramatically. We discuss design challenges for both situations next.

Work Environments: Domain Experts typically perform information exploration and analysis in small groups whose members are already acquainted. There are also typically well defined analysis goals. These goals must be supported by the tabletop software and, hence, the development of specific software may be necessary when datasets and tasks change. In contrast to tabletop systems designed for public spaces, the expectations about interaction techniques and data representations differ in the workplace. The questions in work scenarios are typically quite complex and difficult. Also, the data analysis results might be vital to make important (sometimes time-critical) decisions with many variables to consider. Information visualization interfaces, therefore, typically have a large number of parameters to manipulate. Work teams are often prepared to invest time in learning, and tabletop interfaces designed for these settings can, therefore, often include new interactions and visual designs if they might improve the efficiency and quality of collaborative information exploration. Work teams also often may spend considerable time using an interface, making the effort to learn new techniques worthwhile.

Several information exploration sessions are often necessary to come to a common understanding of a particular dataset in the workplace. Tabletop software for collaborative information exploration should, therefore, support capturing of interaction histories with the information in order to allow groups to interrupt their analysis and continue at a later stage. At the same time, it is often the case that individual group members may drop in and out of a running collaborative information exploration session. For these group members it may also be useful to implement history and summarization mechanisms to show what has been missed. First approaches are incorporated in Lark and Cambiera (see above) [6, 12].

Public Spaces: The audience gathering around a tabletop in a public space can be highly diverse. Visitors of museums and art galleries, for instance, not only differ in age but also in social and cultural background, knowledge, and interests [10]. Furthermore, people often visit exhibitions without clearly defined questions or goals in mind but explore them serendipitously based on spontaneous interest [10]. Interaction with exhibits tends to be brief and usually only occurs once per visitor. This means that tabletop interfaces for information exploration in public settings need to be designed differently from workplace systems. Interaction techniques need to be designed with a walk-up-and-use scenario in mind. Visitors of public spaces are not likely to read elaborate instructions on how to interact with the system but will try to figure out exploration techniques and capabilities of the visualization on the fly. Interaction with the tabletop system therefore should be accompanied by direct feedback mechanisms that encourage further interaction or lead visitors to try different interactive mechanisms. The diversity of people visiting public spaces is often reflected in a variety of interaction times and exploration styles. Some people will only interact with the tabletop installation for a few moments, while others will explore information in detail for a longer amount of time. Therefore, the design of information visualizations on public tabletop

systems should reward both short- and long-term information exploration. Furthermore, some people prefer guided exploration, while others like to follow their personal interests using more open exploration techniques.

4.2 Technological Challenges

In both workplaces and public spaces, hardware challenges exist for the setup of information exploration environments. These challenges relate to size and resolution of the table but also its spatial placement, robustness, and form factor.

Workplace Environments: Domain experts often have to do fine-grained analysis of large and detailed datasets. For the visualization of this data, the size and resolution of a tabletop is critical. As datasets increase in size, it becomes more and more difficult to display them in their entirety. Large and high-resolution tables allow more data to be displayed and support several people working together—either with multiple copies of a data representation or with different parts of a shared visualization. However, detailed and large datasets may require the rendering and reading of small textual labels and other data items. With growing resolution, the displayed information items can become physically smaller resulting in selection difficulties. Using fingers or pens may no longer be sufficient to select small data items and alternative selection techniques may have to be used or designed. Also, when large datasets have to be rendered on high-resolution tabletop screens, combined with several simultaneous inputs, response time may become more important. It is necessary to develop algorithms that can support multi-person interaction on very high resolution tables. Groups of domain experts may also often meet around a digital table to perform long analysis sessions. Therefore, the form factor of the table should be such that it supports comfortable seating positions similar to current meeting spaces in conference rooms or offices.

Public Spaces: Similar to the workspace, public settings can benefit from the availability of large and high-resolution tabletop displays. In public settings, the size of a group wanting to access a table may be much larger than in a workplace. For example, it is not unusual for school classes to gather around a tabletop to interact with and explore information in a museum. In such situations, it is critical that the whole system remains responsive and that the software does not crash, even if 40 hands are touching the table at the same time or even issue conflicting information exploration commands. Tables for public settings also need to be robust in their physical design, be spill-proof and resistant to scratching or pushing. In contrast to domain expert information exploration sessions, one cannot expect children or large groups of adults to treat a public tabletop display with care. It is important to consider that the physical setup of the display (size, orientation, and location) can influence the group size and number of different groups of people interacting with it. Physical form factors also need to be considered with regard to physical accessibility. For instance, all visitors need to be able to see and access the display surface, including children and people in wheelchairs.

4.3 Perceptual Challenges

The environment suggested by a tabletop display is particularly unique to computing systems. In particular, the display has a horizontal orientation and affords multiple people standing at different sides of the table. These properties are compelling for a variety of reasons, but also introduce some unique perceptual challenges. Specifically, the assumption common to desktop computing that there will be one viewer directly in front of the display is no longer valid. For example, Wigdor *et al.* [14] performed a study that suggests that visual variables (e. g., angle, length, shape) are perceived differently on a horizontal surface than on a vertical one. In 3D, the problem is exacerbated, as the projection from 3D onto the 2D surface requires an assumption about the point of view of the (one and only) observer. Thus, a projected image may appear drastically different to observers standing at opposite sides of the table. Several systems have explored solutions to the problem of multiple points of view [1, 7] but the degree of this problem on digital tables has still been largely unexplored.

Some visual elements in both 2D and 3D are particularly sensitive to changes in orientation (e.g., text). Some studies have shown that people are still capable of reading short bits of text at non-zero orientations [13], but they are still slower, and so larger bits of text are best to read in the correct orientation. Other research suggests that the act of orienting visual elements is often used to communicate with others [8] and a variety of methods to perform this act have been introduced to tabletop display environments (see [2] for an overview). Thus, perception of visual elements that have an intrinsic orientation may play an important role in the collaboration that occurs in a tabletop display environment. These perceptual challenges exist in both workplace as well as public settings, but the types of problems that may arise vary somewhat.

Work Environments: Here, the perception of the visual information may be relevant for a variety of reasons. The visual variables used to represent the information may need to precisely depict a value to be judged by the observer, or it may be important to compare two (or more) visual elements. A person on one side of the table may also need to be able to trust that someone across the table can perceive a visual variable in a predictable way (i. e., that their view is not warped in some way). At present, there is little work to suggest how to design systems that address these issues. However, the current work points to the fact that the simple solution of using the same design criteria for vertical displays may not suffice for horizontal ones [14].

Public Spaces: In more artistic or learning environments found in public spaces, the precise value of a particular visual element may not be as important as in systems designed for domain expert analysis in the workplace. Instead, it may be more important for the designer to consider the fact that the perceptual experience of two observers standing at opposite sides of the table will differ. This difference in experience can be thought of as an additional challenge for the designer; the system can be made to either mitigate these perceptual differences, or to take advantage of them in order to create a unique experience for the observers. Nonetheless, the consideration of the orientation of the visual elements can be particularly important in a public space. Grabbing the attention of someone passing by will involve the consideration of how the display looks from both far away and from close proximity. Orientation-sensitive elements, such as text, may play an important role in drawing attention, indicating a suitable viewpoint, or to help encourage communication between multiple simultaneous observers.

4.4 Collaborative Challenges

Several previous studies of collaborative information exploration, both for work environments [11] as well as public spaces [3], suggest a need to support a wide range of collaboration styles. People may be interested in exploring parts of the information by themselves without interfering with other people but may, at any given time, switch from this parallel work to a phase in which they work more closely together, sharing information items, and discussing them closely. Despite these initial similarities, the information exploration goals and contextual exploration scenarios for information visualization in work environments and public spaces form different design challenges.

Work Environments: If one wants to support collaborative information exploration, one has to either design visual representations that support synchronous interaction or that allow for the ability to create several interactive views of the same dataset. Global changes to views and encodings of data are fairly common in single-user visualization systems and if one is interested in re-designing such an application for tabletop use, the re-design of these features for synchronous group work is critical [6].

Since, the datasets used in expert systems are often large, complex, uncertain, and subject to different interpretations, people have to pay close attention to the data they may be working with in order to keep their exploration context and intermediate findings in memory. Thus,

for information exploration tasks, the physical cues naturally available in a co-located environment only provide limited support for awareness and common ground formation. Team members may still be able to see each others' hand and arm movements, gestures, and hear their incidental comments about data, but when the complexity of the information visualization requires increased concentration, these awareness cues may be missed. For example, a person may be pointing to a specific data item in a visualization and make a comment about it but another person may be too focused to pay attention to which item it is, what its context is within the dataset, or even which dataset it is from. When designing interfaces and visual representations for collaborative information exploration, we thus need to ensure that people can simultaneously concentrate on the complex data and maintain an awareness of each others' work and activities. Mechanisms may have to be put in place to support better contextual understanding for the reference of data items.

Large and complex datasets place a high cognitive load on the viewers. It is, therefore, important that collaborators can externalize some of their findings easily and, for example, annotate the data to mark a finding or to rate the reliability, trustworthiness, or certainty of a data item. This externalization is particularly important for collaborative data analysis because individuals may, on a momentary notice, switch context, work with another person, and then have to return to their previous work. Keeping an integrated exploration history together with data annotations could greatly support this type of expert information exploration.

Public Spaces: Museum studies have found that people often visit public exhibitions in groups. The studies conducted by Hinrichs et al. [3] and Hornecker et al. [4] confirm this finding for tabletop installations within museum settings. The physical setting of a tabletop display allows different visitor groups to approach the installation from all sides. When several people interact with a tabletop display at the same time, however, it is hard to maintain awareness of who is exploring what part of the visualization. In a public setting, this awareness is even more compromised since it is less likely for visitors who do not know each other to communicate or pay attention to each other and, hence, the possibility of interaction conflict is high. Different public tabletop systems deal with this problem in different ways. floating.numbers (http://www.artcom.de) and memory [en]code [9] both involve visualizations that consist of independent information objects; people can interact with different objects without interfering with each other. The visualization in EMDialog [3] was not designed to support several people exploring it in parallel, hence, the physical setup of the installation did not to invite parallel information exploration among unacquainted people. As a third example, information presented on the Tree of Life table is divided in four quadrants [4] to allow four different groups of people to explore it without interfering with each other. These examples show that there is a variety of ways to enable parallel independent information exploration.

Group interaction in public settings also is less focused around maximizing insights from the visualization and more about experiencing information collaboratively in a social way. When collaboratively exploring a museum exhibit, social interaction and sharing information can play an important role. Parents, for instance, often use information exhibits to explain causalities within the information to their children [4]. While in this situation often only one person is interacting at a time, the process of information exploration is still highly collaborative. Similar forms of collaboration can be observed among adults when they are still unclear of what an installation has to offer and how to interact with it. Groups also explore visualizations in parallel and, from time to time, share their insights through discussion, whereas others go through all information together.

5 Summary

It is likely that future technology will become even more ubiquitous in our environments and that it will come in many different form factors. Humans have considerable experience and expertise working together on physical tables, making this form factor a particularly promising one to promote. At the same time, we are collecting more diverse sets of information than ever before. Much of this information is being collected for the purpose of being explored interactively. Tabletop displays combine the benefits of a large display area for information, enough space for several people to share, and a seating or standing arrangement that allows for easy discussion and interaction among group members. Supporting collaborative information exploration will become an extremely important task for future systems in a large number of different settings.

We have discussed contextual, technological, perceptual and collaborative challenges arising when designing tabletop systems for information exploration in two different contexts: workplace settings where domain experts gather to explore and analyse often large and complex datasets, and public spaces where the design has to support a much more diverse set of people, tasks, and goals. While several issues are common in both settings, other challenges are unique to workplace environments or public spaces and need to be addressed accordingly.

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